CSCE 463/612
Networks and Distributed Processing
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Network Layer

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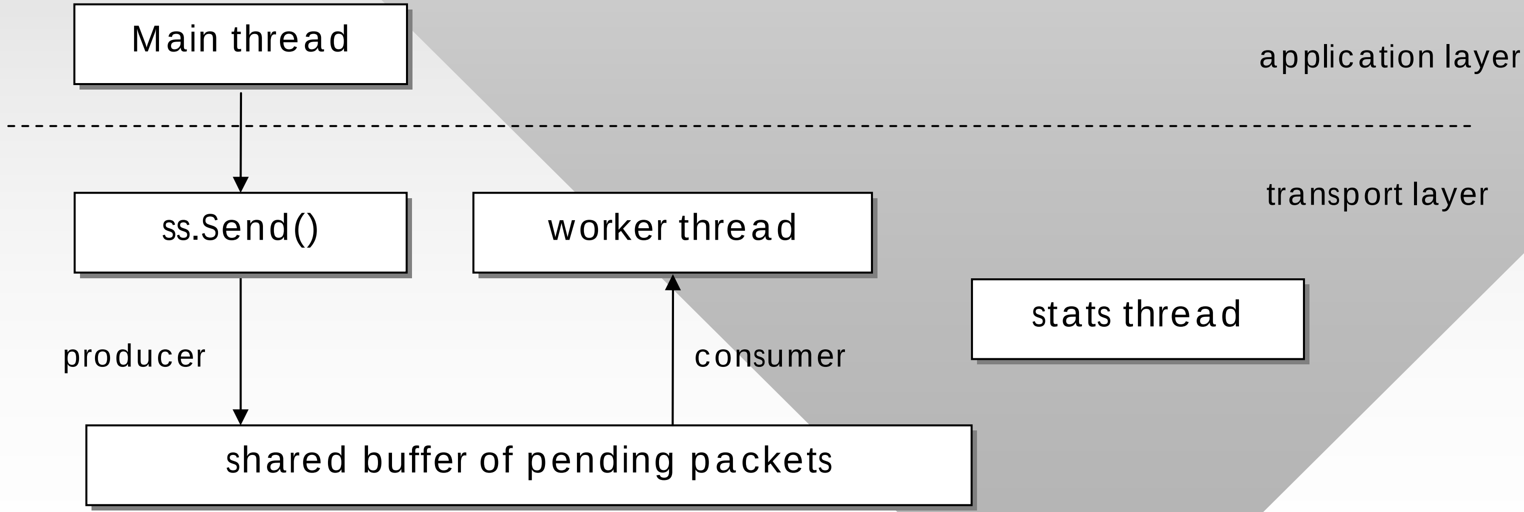
Homework #3

- Reliable data transfer between two processes
  - ss.Send() is the producer into a bounded buffer of W packets (W = sender window)
  - Worker thread is the consumer from this buffer (ACK arrival that moves sndBase by X pkts releases X slots in buffer)
  - Requires two semaphores



Homework #3

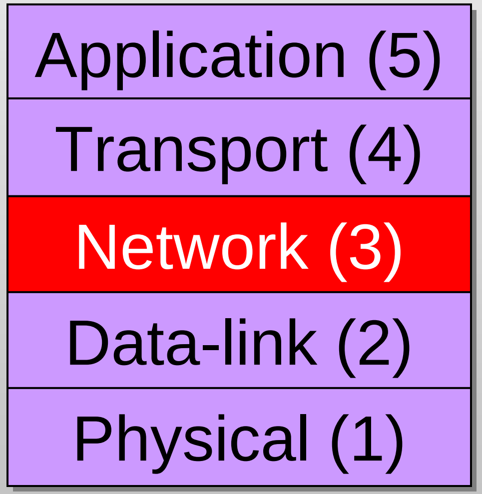
- Interesting aspect is how to release semaphore to accommodate flow control
  - Assume sndBase, nextSeq, W are known
  - Receive ACK with sequence y > sndBase, recvWnd = R
  - By how much to release semaphore?

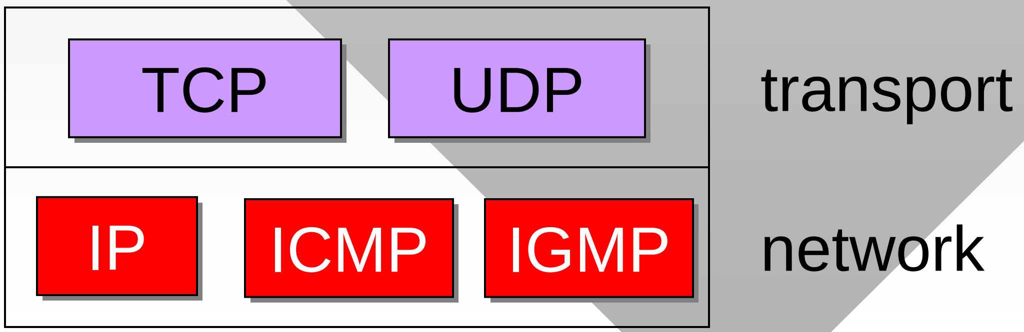
```
lastReleased = 0;
sndBase = -1;       // SYN-ACK 0 will move this to 0
while (not end of transfer)
{
    get ACK or SYN-ACK with sequence y, receiver window R
    if (y > sndBase)
    {
          sndBase = y
          effectiveWin = min (W, R)
          // how much we can advance the semaphore
          newReleased = sndBase + effectiveWin - lastReleased;
          ReleaseSemaphore (s, newReleased);
          lastReleased += newReleased;
    }
}
```

Chapter 4: Network Layer

Chapter goals:

- Understand principles behind network layer services:
  - How a router works (forwarding)
  - Routing (path selection)
  - Dealing with scale
  - Other topics: IPv6, multicasting
- Traceroute program as hw#4
- Big picture:





Chapter 4: Roadmap

4.1 Introduction

4.2 Virtual circuit and datagram networks

4.3 What's inside a router

4.4 IP: Internet Protocol

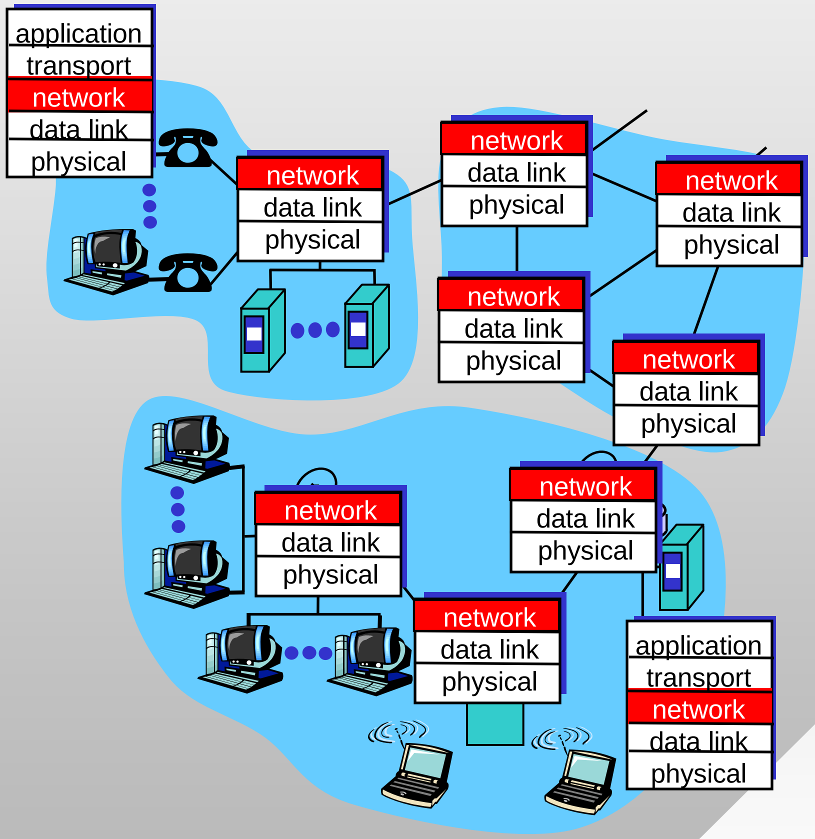
4.5 Routing algorithms

4.6 Routing in the Internet

4.7 Broadcast and multicast routing

Network Layer = IP Layer

- Transports segments from sending to receiving host
- On the sending side, encapsulates segments into datagrams
- On the receiving side, delivers segments to transport layer
- Network layer protocols in *every* host and router
- Router examines header fields in all IP datagrams passing through it

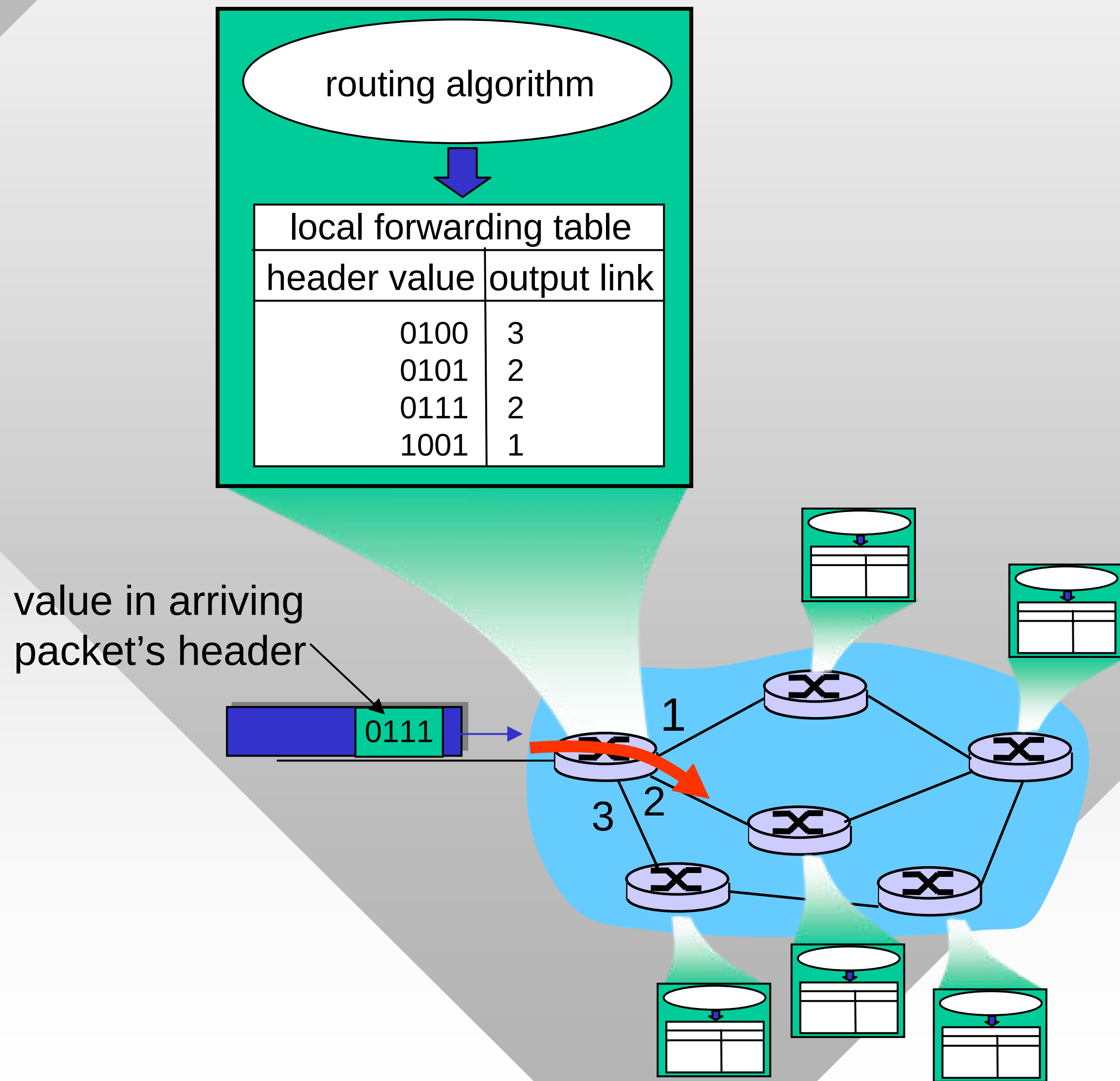


Key Network-Layer Functions

- 1) *Routing:* determine the path taken by packets from source to dest
  - Build a minimum-cost table at each router
  - Table has next-hop neighbor for each possible destination
  - Goal: send packet along the least-expensive path (e.g., in terms of hops, ISPs, or peering agreements)
- 2) *Forwarding:* move packets from a router's input port to appropriate router output port
  - Table lookup
  - Port-to-port transfer
  - Goal: efficiency

physical interface (NIC) inside router, not a TCP/UDP port!

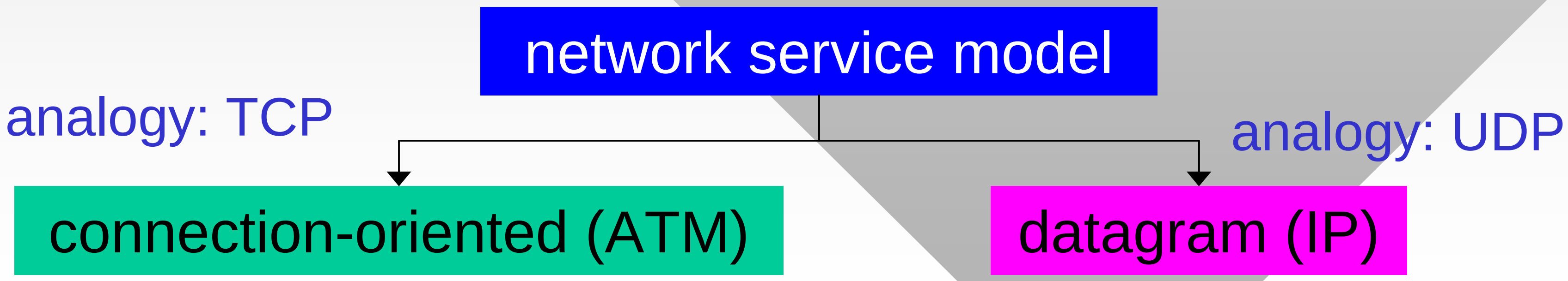
Interplay Between Routing and Forwarding



local forwarding table	
header value	output link
0100	3
0101	2
0111	2
1001	1

Connection Setup (ATM)

- *3) Connection setup* in certain network architectures:
  - e.g., ATM (Asynchronous Transfer Mode)
- Before datagrams flow in such networks, two hosts and intermediate routers establish virtual circuit (VC)
  - Routers get involved to set up a path
- Network and transport layer connection service:
  - Network: between two hosts
  - Transport: between two processes

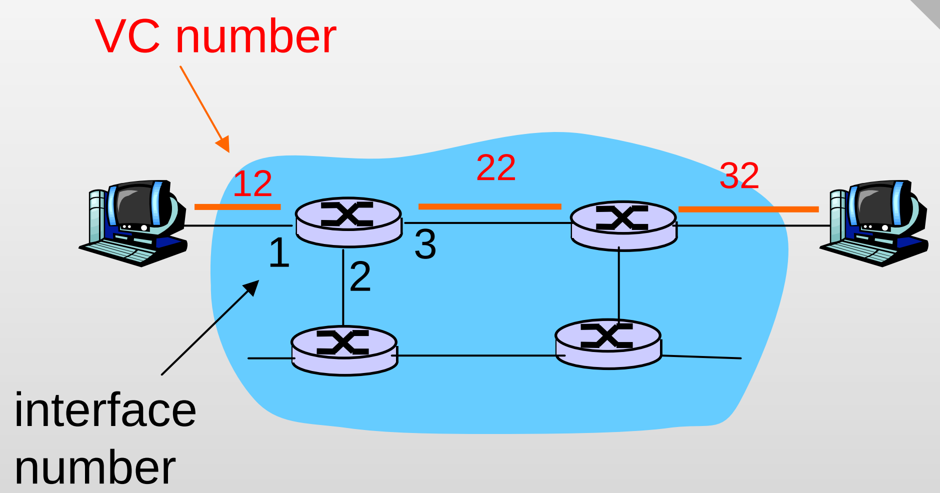


Chapter 4: Roadmap

Virtual Circuits

- VCs may create a path that behaves much like a telephone circuit (no congestion, low delay, no loss)
- Call setup for each connection *before* data can flow
  - Similar to TCP's handshake, but involves routers
- Each packet carries a VC tag instead of the 5-tuple <src addr, dest addr, src port, dest port, proto>
- *Every* router on source-dest path maintains "state" for each passing connection
  - Mapping from tags to next-hop router
- Fraction of router resources (bandwidth, buffers) are allocated to each VC

Forwarding Table



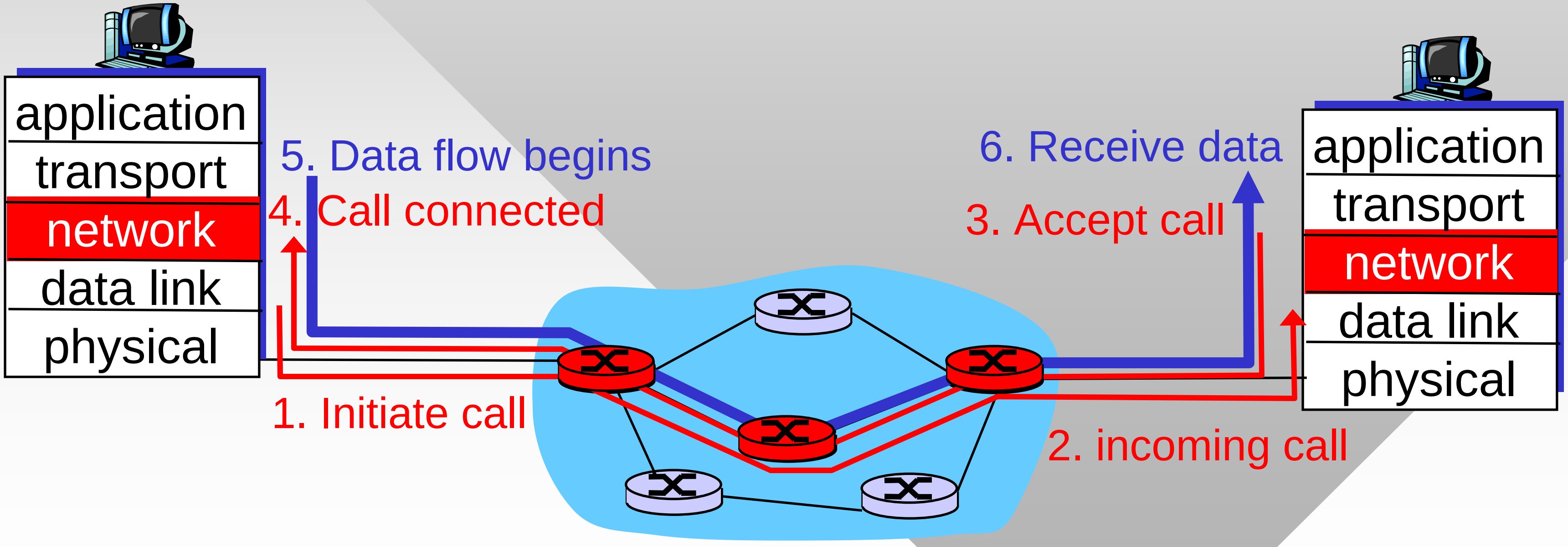
Forwarding table in northwest router:

Incoming interface	Incoming VC #	Outgoing interface	Outgoing VC #
1	12	3	22
2	63	1	18
3	7	2	17
1	97	3	87
…	…	…	…

Routers maintain connection state information!

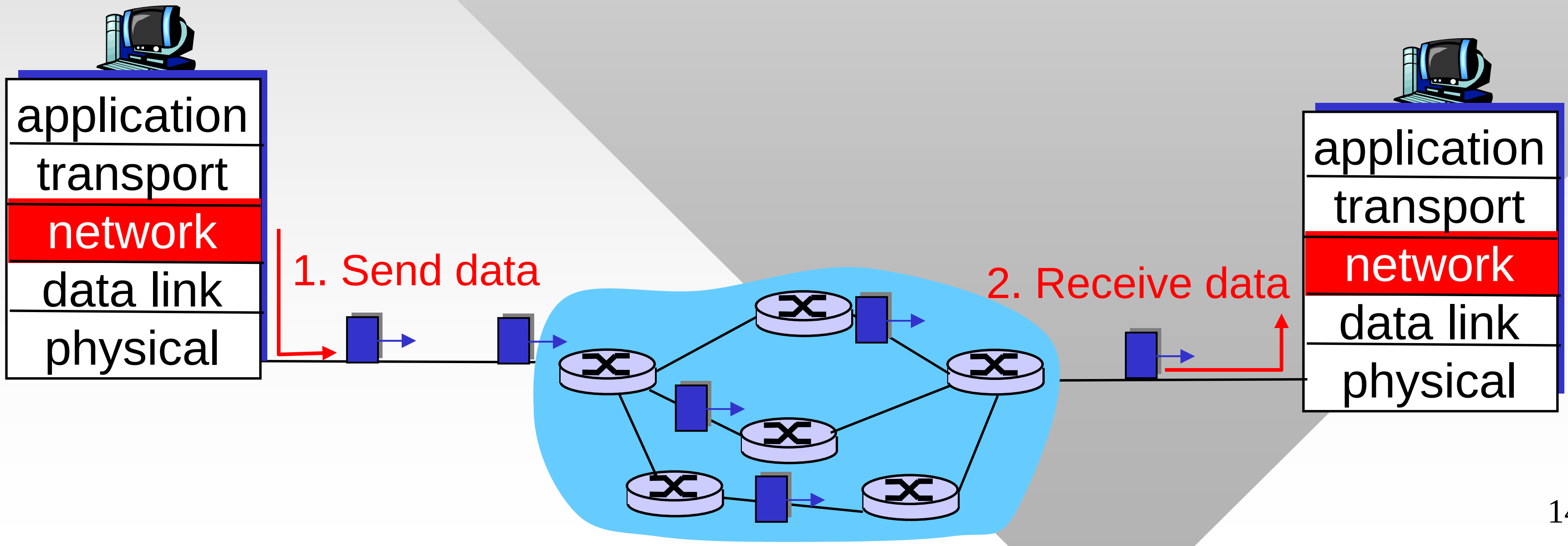
Virtual Circuits: Signaling Protocols

- Setup, maintain, teardown VC
- Used in ATM, frame-relay, etc.
- Not used end-to-end in today's Internet



Datagram Networks

- No call setup at network layer
- Routers: no state about end-to-end connections
  - No network-level concept of “connection”
- Packets forwarded using destination host address
  - Packets between the same source-dest pair may take different paths (multi-path routing)



Datagram Forwarding Table

4 billion possible entries

Destination Address Range (32 bit)	Link Interface
11001000 00010111 00010000 00000000 through 11001000 00010111 00010111 11111111	0
11001000 00010111 00011000 00000000 through 11001000 00010111 00011000 11111111	1
11001000 00010111 00011000 00000000 through 11001000 00010111 00011111 11111111	2
otherwise	3

Longest Prefix Matching

Prefix Match	Link Interface
11001000 00010111 00010	0
11001000 00010111 00011000	1
11001000 00010111 00011	2
otherwise	3

Examples (DA = destination address)

DA: 11001000 00010111 00010110 10100001
DA: 11001000 00010111 00011001 10101010
DA: 11001000 00010111 00011000 10101010

Which interface?

Datagram or VC Network: Why?

Internet

- Driven by data exchange among computers
  - “Elastic” service, no strict timing requirements
- “Smart” end systems (computers)
  - Can adapt, perform control, error recovery
  - Simple network core, complexity at “edge”
- Many link types
  - Different characteristics
  - Uniform service difficult

ATM

- Evolved from telephony
- Human conversation:
  - Strict timing, bandwidth requirements
  - Need for guaranteed service
- “Dumb” end systems
  - Telephones
  - Complexity in network core